

## CLAIMS

1. A bonding method for bonding objects to be bonded together in a solid phase at 500°C or less after subjecting bonding surfaces of the objects to be bonded to a hydrophilic treatment using a plasma, wherein

a chemical treatment step of subjecting both said objects to be bonded to a chemical treatment using a plasma having a weak ion strike force is performed

after a physical treatment step of subjecting both said objects to be bonded to a physical treatment using an energy wave having a strong ion strike force, said energy wave being an atom beam, an ion beam or a plasma, thereby bonding both said objects to be bonded together.

2. The bonding method according to claim 1, wherein an energy wave of said physical treatment step is a plasma.

3. The bonding method according to claim 1 or 2, wherein a reaction gas of said chemical treatment step is oxygen or nitrogen.

4. The bonding method according to any of claims 1 to 3, wherein, after said physical treatment step, evacuation is performed before said chemical treatment step.

5. The bonding method according to claims 1 to 4, wherein, during or after said chemical treatment, a gas containing  $H_2O$  or H or OH groups is introduced and mixed before bonding.

6. The bonding method according to any of claims 1 to 5, wherein a reaction gas of said physical treatment step is different from a gas of said chemical treatment step, and is Ar or  $CF_4$ .

7. The bonding method according to any of claims 1 to 6, wherein said physical treatment step and said chemical treatment step are performed without exposure to the atmospheric air.

8. The bonding method according to any of claims 2 to 5, wherein by means of a plasma treatment means for changing the ion strike force,

said physical treatment is performed in a first half of a plasma treatment, the ion strike force is reduced in a second half of a plasma treatment so that said chemical treatment is promoted.

9. The bonding method according to claim 8, wherein said plasma treatment means for changing the ion strike force comprises a plasma electrode including an object-to-be-bonded holding electrode and a

counter surface electrode which are provided at two positions and can be used for said plasma electrode alternatively,

a power supply is applied to said object-to-be-bonded holding electrode to generate a low-pressure plasma, thereby performing a plasma treatment for performing said physical treatment,

and thereafter, said power supply is applied to said counter surface electrode to reduce the ion strike force, thereby performing a plasma treatment for promoting said chemical treatment.

10. The bonding method according to claim 8, wherein said plasma treatment means for changing the ion strike force comprises an RF plasma power supply capable of adjusting a Vdc value,

said Vdc value of said RF plasma power supply is changed in said second half of the plasma treatment to reduce the ion strike force of a low-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

11. The bonding method according to claim 8, wherein said plasma treatment means for changing the ion strike force comprises a pulsed-wave plasma power supply capable of adjusting a pulse width,

said pulse width of said a pulsed-wave plasma power supply is changed in said second half of the plasma treatment to reduce the ion strike force of a low-pressure plasma so that a plasma treatment for promoting

said chemical treatment is performed.

12. The bonding method according to 8, wherein said plasma treatment means for changing the ion strike force comprises a first and a second low-pressure plasma emitting means each of which emits a low-pressure plasma having a different ion strike force; and means for switching between said first and said second low-pressure plasma emitting means,

a power supply is applied to an object-to-be-bonded holding electrode of said first low-pressure plasma emitting means in said first half of the plasma treatment to generate a low-pressure plasma, thereby performing a plasma treatment for performing said physical treatment,

in said second half of the plasma treatment, said first low-pressure plasma emitting means is switched to said second low-pressure plasma emitting means which traps plasma ions generated in another room and emits radicals, thereby reducing the ion strike force so that a plasma treatment for promoting said chemical treatment is performed.

13. The bonding method according to claim 8, wherein said plasma treatment means for changing the ion strike force is means for switching between a low-pressure plasma and an atmospheric-pressure plasma,

after subjecting said surfaces of the objects to be bonded to said

physical treatment with an ion strike force enhanced by said low-pressure plasma,

the ion strike force is reduced with said atmospheric-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

14. The bonding method according to any of claims 8 to 13, wherein a reaction gas is a mixed gas containing oxygen and nitrogen.

15. The bonding method according to any of claims 8 to 13, wherein a plasma reaction gas is switched from a reaction gas containing oxygen to a reaction gas containing nitrogen during a plasma treatment using a reduced ion strike force in said second half of the plasma treatment.

16. The bonding method according to any of claims 1 to 15, wherein, during said bonding, a voltage is applied between both said objects to be bonded so that said objects to be bonded are bonded together in a solid phase while being heated.

17. The bonding method according to any of claims 1 to 16, wherein at least one of said objects to be bonded is made of Si, SiO<sub>2</sub>, glass or ceramic.

18. The bonding method according to any of claims 1 to 17, wherein said object to be bonded is a wafer or a chip cut off from a wafer.

19. A device, such as a semiconductor device, an MEMS device or the like, which is produced using the bonding method according to any of claims 1 to 18.

20. A surface activating unit for subjecting bonding surfaces of objects to be bonded to a hydrophilic treatment using a plasma for bonding said objects to be bonded together in a solid phase at 500°C or less, said unit comprising:

an energy wave emitting means for performing a chemical treatment step of subjecting both said objects to be bonded to a chemical treatment using a plasma having a weak ion strike force

after a physical treatment step of subjecting both said objects to be bonded to a physical treatment using an energy wave having a strong ion strike force, said energy wave being an atom beam, an ion beam or a plasma.

21. The surface activating unit according to claim 20, wherein said energy wave emitting means is a plasma emitting means, said energy wave of said physical treatment step is a plasma generated by said plasma emitting means.

22. The surface activating unit according to claim 20 or 21, wherein a reaction gas of said chemical treatment step is oxygen or nitrogen.

23. The surface activating unit according to any of claims 20 to 22, wherein, after said physical treatment step, evacuation is performed before said chemical treatment step.

24. The surface activating unit according to claims 20 to 23, comprising a water gas generating means, wherein, during or after said chemical treatment, a gas containing  $H_2O$  or H and OH groups is introduced and mixed before bonding.

25. The surface activating unit according to any of claims 20 to 24, wherein a reaction gas of said physical treatment step is different from a gas of said chemical treatment step, and is Ar or  $CF_4$ .

26. The surface activating unit according to any of claims 20 to 25, wherein said physical treatment step and said chemical treatment step are performed without exposure to the atmospheric air.

27. The surface activating unit according to any of claims 21 to

24, comprising a plasma treatment means for changing the ion strike force, which functions as said plasma emitting means, wherein by means of said plasma treatment means,

said physical treatment is performed in a first half of a plasma treatment, the ion strike force is reduced in a second half of a plasma treatment so that said chemical treatment is promoted.

28. The surface activating unit according to claim 27, wherein said plasma treatment means for changing the ion strike force comprises a plasma electrode including an object-to-be-bonded holding electrode and a counter surface electrode which are provided at two positions and can be used for said plasma electrode alternatively,

a power supply is applied to said object-to-be-bonded holding electrode to generate a low-pressure plasma, thereby performing a plasma treatment for performing said physical treatment,

and thereafter, said power supply is applied to said counter surface electrode to reduce the ion strike force, thereby performing a plasma treatment for promoting said chemical treatment.

29. The surface activating unit according to claim 27, wherein said plasma treatment means for changing the ion strike force comprises an RF plasma power supply capable of adjusting a Vdc value,

said Vdc value of said RF plasma power supply is changed in said



second half of the plasma treatment to reduce the ion strike force of a low-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

30. The surface activating unit according to claim 27, wherein said plasma treatment means for changing the ion strike force comprises a pulsed-wave plasma power supply capable of adjusting a pulse width,

said pulse width of said a pulsed-wave plasma power supply is changed in said second half of the plasma treatment to reduce the ion strike force of a low-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

31. The surface activating unit according to 27, wherein said plasma treatment means for changing the ion strike force comprises a first and a second low-pressure plasma emitting means each of which emits a low-pressure plasma having a different ion strike force; and means for switching between said first and said second low-pressure plasma emitting means,

a power supply is applied to an object-to-be-bonded holding electrode of said first low-pressure plasma emitting means in said first half of the plasma treatment to generate a low-pressure plasma, thereby performing a plasma treatment for performing said physical treatment,

in said second half of the plasma treatment, said first low-pressure

plasma emitting means is switched to said second low-pressure plasma emitting means which traps plasma ions generated in another room and emits radicals, thereby reducing the ion strike force so that a plasma treatment for promoting said chemical treatment is performed.

32. The surface activating unit according to claim 27, wherein said plasma treatment means for changing the ion strike force is means for switching between a low-pressure plasma and an atmospheric-pressure plasma,

after subjecting said surfaces of the objects to be bonded to said physical treatment with an ion strike force enhanced by said low-pressure plasma,

the ion strike force is reduced with said atmospheric-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

33. The surface activating unit according to any of claims 27 to 32, wherein a reaction gas is a mixed gas containing oxygen and nitrogen.

34. The surface activating unit according to any of claims 27 to 32, wherein a plasma reaction gas is switched from a reaction gas containing oxygen to a reaction gas containing nitrogen during a plasma treatment using a reduced ion strike force in said second half of the plasma

treatment.

35. The surface activating unit according to any of claims 20 to 34, wherein, during the bonding, a voltage is applied between both said objects to be bonded so that said objects to be bonded are bonded together in a solid phase while being heated.

36. The surface activating unit according to any of claims 20 to 35, wherein at least one of said objects to be bonded is made of Si, SiO<sub>2</sub>, glass or ceramic.

37. The surface activating unit according to any of claims 20 to 36, wherein said object to be bonded is a wafer or a chip cut off from a wafer.

38. A bonding apparatus comprising:  
said surface activating unit according to any of claims 20 to 37; and  
means for bonding both said objects to be bonded together, wherein  
said apparatus collectively performs from said hydrophilic treatment using said surface activating unit to said bonding using said means for bonding.